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PATENT SPECIFICATION

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319,313

COMPLETE SPECIFICATION.

The Regulation of the Electric Potential of Long Lines.

We, SIEMENS - SCHUCKERTWERKE AKTIENGESELLSCHAFT, a German Company, of Berlin-Siemensstadt, Germany, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In alternating current long distance lines as is well known the tension increases greatly when running idle, because the charging current causes a rise in tension in the line (Ferranti-effect): on the other hand in the loaded state a drop in tension is caused by the load current. The increase in tension through the Ferranti-effect and the drop in tension owing to the load current cause a change in tension, which alters in sympathy with the load. In order to keep the tension constant also under varying loads, this change in tension must be again counter-balanced by means of suitable compensating devices and it has already been proposed to regulate these compensating devices in dependence on the tension of the long distance line.

In contradistinction to the regulation already known by voltage sensitive regulators, according to the invention these compensating devices, which are distributed along the line section by section at different stations, are so controlled by regulating devices directly sensitive to the ratio of voltage to current of the long distance line that $\sqrt{\frac{L}{C}}$ is always equal to $\frac{E}{J}$, where ωL is the effective series reactance of the long distance line including the reactance of the compensating devices and consumers ωC the reciprocal of the effective parallel reactance of the long distance line including the reactance of the compensating devices and consumers, E the tension, J the current and ω the 2π fold of the frequency.

Instead of the working current (J) the total current may also act upon the regulating member because the total current in particular under strong load only differs very slightly from the real working current because the total current is not the algebraic but the geometric sum or total resulting from working and wattless currents.

As already stated the wattless currents of the consumers are to be classed together with the compensating reactances in the quantities L and C in the formula. As the consumer generally always lies parallel to the line, then in this case, by means of the additional reactance which is generated by the wattless currents of the consumer, only the parallel reactance of the line $\left(\frac{1}{\omega C}\right)$ is altered

Generally speaking the wattless currents of the consumers are constant so that they can be at once taken into consideration in adjusting the regulating means. If the wattless currents of the consumers vary a medium or average value is taken and the reactance of the consumers is taken to be the reactance corresponding to this average value.

The regulation according to the invention presents, in comparison with the control in dependence on the tension alone, the advantage that it is much more sensitive because in the event of a change to be made in the energy to be transmitted not only the tension but pre-eminently the current changes very greatly.

In the case of alternating current long distance lines, in which the generators of the power station are regulated to constant tension, the arrangement according to the invention as set out above may be modified in that the regulation of the compensating devices is effected solely in dependence on the current (total or working current) of the long distance line. The coil which effects the movement of the regulating element of the regulator is in this case influenced by a current which is in proportion to the current of the long distance line.

The regulation according to the invention has as a basis the fact that the potential on the line, above all in the stations in which the compensation arrangements are situated, remains prac-

SEE ERRATA SLIP ATTACHED

tically constant when the proportion of potential to current is equal to the characteristic impedance of the line, i.e. equal to the root of the ratio of L to C. According to the ratio of L and C, the compensating device is put in shunt to the network mains (Case A) (Figure 1) or in series with the network mains (Case B) (Figure 2). It may often be advisable to put the compensating devices both in parallel to, as well as in series with, the network mains (Case A and Case B).

The additional reactance supplied by the compensating device may be either capacitative or inductive. If the additional reactance be capacitative and, if the parallel capacity of the line is indicated by C^1 according to Figure 1, and the additional parallel capacity supplied by the compensating arrangement by C^{11}, then for case A we get the formula

$$1.)\quad C^1 + C^{11} = L.\frac{J^2}{E^2}$$

As the parallel capacity C^1 of the net and the series inductance L of the net are constant, and as the tension E is to be maintained constant, hence C^{11} is dependent upon J^2.

If the additional parallel reactance supplied from the compensating device lying parallel to the line be inductive and if L_p be used to indicate the parallel inductance of the compensating arrangement, then we get the formula

$$2.)\quad C^1 - \frac{1}{\omega^2 L_p} = L\frac{J^2}{E^2},\ \text{hence}$$

$$3.)\quad L_p = \frac{1}{\omega^2\left(C^1 - L\frac{J^2}{E^2}\right)}$$

L_p is also dependent upon J^2.

If the compensating arrangements be mounted in the line in series (Figure 2) and if the additional series reactance supplied by the compensating arrangement be inductive, and if L^{11} be used to indicate the additional series inductance supplied by the compensating arrangement and with L^1 the series inductance of the line, then for case B we get the formula

$$4.)\quad L^1 + L^{11} = C\frac{E^3}{J^2}$$

As the series inductance L^1 of the wire and the parallel capacity C of the line are constant and the tension E is to be maintained constant, hence L^{11} is dependent upon J^2.

If the additional series reactance supplied by the compensating arrangement be capacitative and if the series capacity of the compensating device be indicated by C_r, then we get the formula

$$5.)\quad L^1 - \frac{1}{\omega^2 C_r} = C\frac{E^2}{J^2},\ \text{hence}$$

$$6.)\quad C_r = \frac{1}{\omega^2\left(L^1 - C\frac{E^2}{J^2}\right)}$$

C_r is also dependent upon J^2.

The compensating device may consist of a synchronous or an asynchronous machine the excitation of which is correspondingly controlled. It is of course also possible to use adjustable choking coils or condensers as compensating devices.

Figure 3 shows an example of carrying out the invention. In the figure, only one station with its compensating and regulating apparatus is shown, as the arrangement with the other stations is the same. The compensating arrangement consists in the example shown, of the synchronous machine 2, the energising of which may be adjusted by the field rheostat 4. According to the position of this regulator, the synchronous machine supplies a larger or a smaller wattless current. The current relay 3 serves to adjust the regulating resistance. The current relay is in the example shown, imagined as a Ferrari relay and has a disc 31, the position of which depends on the value of the current J of the line. This disc can be fitted on a common axis with the contact arm of the regulating resistance, so that to each position of the disc there corresponds a perfectly definite adjustment of the regulating resistance. The coupling between disc and resistance may also take place electrically, for example a magnet might act on the contact arm of the regulating resistance against the force of a spring, which magnet would tend to rotate the contact arm out of its normal position, and the strength of the energising current of which depends on the position of the disc. (On rotating the disc, for example, more or less resistance is switched into the energising circuit of this magnet). By means of this mechanical or electrical coupling, a definite position of the regulating resistance is made to correspond to each position of the rotating disc.

The amounts of the wattless current with different energising can be taken from the known characteristic of the machine. By suitable construction of the regulating resistance (or with a given regulating resistance by a suitable construction of the relay) the result can be attained that for each position of the current relay 3 the synchronous machine supplies so much wattless output into the line that the value $\sqrt{\frac{L}{C}}$ is always equal to $\frac{E}{J}$, with the example

chosen, L being the series inductance of the line, and ωC the reciprocal of the effective parallel reactance including the supplementary capacity or inductance supplied by the compensating arrangement.

A quotient relay may also be used for controlling the compensating arrangement, that is, a relay which is influenced by the ratio of potential to current.

The adjustment of the current J_k supplied by the compensating arrangement, is given according to the formula

$$J_k = \frac{E}{\omega L_p} = E.\omega\left(C^1 - L.\frac{J^2}{E^2}\right) \quad (5)$$

Equation 5 is given from equation 3. In equation 5 the value of the parallel inductance to be supplied by the compensating arrangement is given. As the potential E of the line is to be kept constant, therefore the wattless current J_k to be supplied by the machine is equal to $\frac{E}{\omega . L_p}$. If the value for L_p is inserted from equation 3, then equation 5 is obtained. As in the use of a synchronous or asynchronous machine as compensating apparatus the stator idle current J_k namely, the wattless current supplied to the line by the asynchronous or synchronous machine, clearly depends on the energising current of the idle current machine, it is therefore only necessary to arrange such a definite connection between the energising current or its regulator and the rotating disc 31 of the current relay 3 that J_k varies as the square of the watt current J in the line according to equation 5.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. Arrangement for the regulation of tension of alternating current long distance lines by means of compensating devices distributed along the long distance line, which supply the Wattless power required for the regulation of the tension, characterised by regulating devices for these compensating devices, which regulating devices are directly sensitive to the ratio of voltage to current of the long distance line and so control the compensating devices that $\sqrt{\frac{L}{C}} = \frac{E}{J}$ where ωL is the effective series reactance of the long distance line including the reactance of the compensating devices and consumers, ωC is the reciprocal of the effective parallel reactance of the long distance line including the reactance of the compensating devices and consumers, E the tension, J the current and ω the 2π fold of the frequency.

2. The arrangement according to claim 1, for alternating current long distance lines in which the generators in the generator station are regulated to constant tension, modified in that the adjustment of the compensating devices is effected solely in dependance upon the current (total or working current) of the long distance line, the coil effecting the moving of the controlling element of the regulator being supplied by current proportional to the current of the long distance line.

3. Arrangement according to claim 1, characterised by the compensating devices being in parallel to the long distance line.

4. Arrangement according to claim 1, characterised by the compensating devices being in series with the long distance line.

5. Arrangement according to claim 1, characterised by compensating devices being provided both parallel to as well as in series with the line.

6. An arrangement according to claim 3, characterised by the fact that the compensating contrivance is so controlled that its parallel inductance L_p changes in accordance with the equation

$$L_p = \frac{1}{\omega^2\left(C^1 - L^1\frac{J^2}{E^2}\right)}$$

whilst C^1 is the capacity of the long distance line, L^1 the inductance of the long distance line, E the tension, J the current of the long distance line and ω the 2π-fold of the frequency.

7. Arrangement according to claims 1 and 4, characterised by the fact that the compensating contrivance is so controlled that its series capacity C_r changes in accordance with the equation

$$C_r = \frac{1}{\omega^2\left(L^1 - C.\frac{E^2}{J^2}\right)}$$

whilst L^1 is the inductance, C the capacity, E the tension, J the current of the long distance line and ω the 2π-fold of the frequency.

8. Regulation of the electric potential of long lines substantially as herein described with reference to and as illustrated by the accompanying drawing.

Dated this 18th day of January, 1929.

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and
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Agents for the Applicants.

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ERRATUM.

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In the heading on Page 1, *for* "July 18, 1929" *read* "July 18, 1930"

[This Drawing is a reproduction of the Original on a reduced scale]

Fig. 1

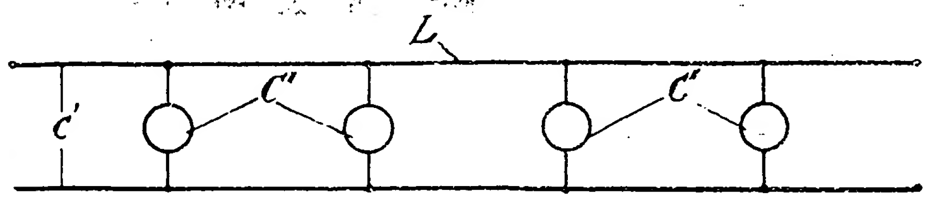


Fig. 2

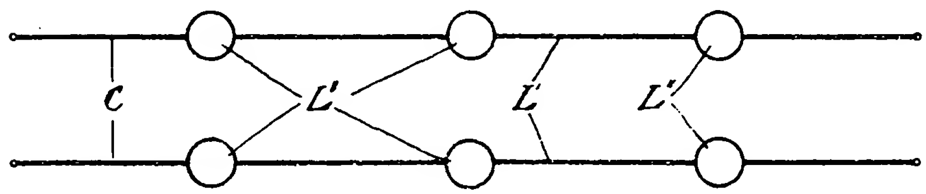
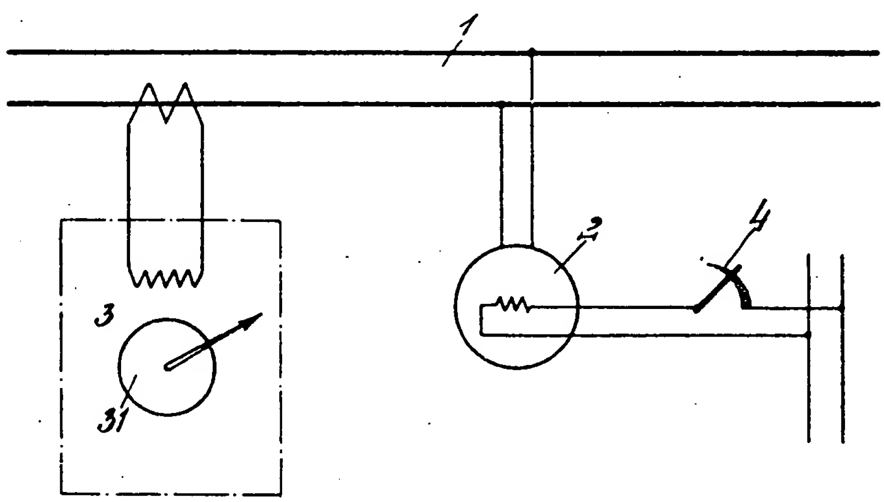


Fig. 3



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